

# Health Security Success in Primary Health Care Services Delivery by the Administration of His Excellency Ahmed Usman Ododo, Governor of Kogi State (2022–2025)

Dr Mu'azu Omeiza Musa, MBBS<sup>1</sup>, Professor Olugbenga-Bello Adenike, MBBS, PhD<sup>2</sup>, Adah Patrick Enejo, MPH<sup>3</sup>, Dr Onoja-Alexander Mary Ojonema, MBBS, PhD FWACP<sup>4</sup>, Dr Emmanuel Bola Jonah K., MBBS, MPH, PhD<sup>5</sup>, Dr Akpa Francis, MBBS, MPH, FWACP<sup>6</sup>, Adah William Arome, MSc<sup>7</sup>

<sup>1</sup>ED, Kogi State Primary Health Care Development Agency (KSPHCDA), Nigeria

<sup>2</sup>Dean, College of Clinical Sciences, Ladoke Akintola University of Technology (LAUTECH), Ogbomoso, Oyo State, Nigeria

<sup>3</sup>DHPRS, Kogi State Primary Health Care Development Agency (KSPHCDA), Nigeria

<sup>4</sup>Reader/Consultant, Community Medicine, College of Health Sciences, Federal University of Lokoja (FUL), Kogi State, Nigeria

<sup>5</sup>SWAp Focal Person, Kogi State Ministry of Health, Nigeria

<sup>6</sup>DPH, Kogi State Ministry of Health (KSMoH), Nigeria

<sup>7</sup>Lecturer II, Department of Computer Science, Faculty of Computing and Informatics, Confluence University of Science and Technology (CUSTECH), Osara Kogi State, Nigeria

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## ABSTRACT

Strengthening Primary Health Care (PHC) financing, governance, and operational readiness is fundamental to achieving resilient health systems and sustainable health security in low- and middle-income countries. Between 2022 and 2025, the Kogi State Government implemented a package of PHC reforms comprising Decentralized Facility Financing (DFF), the Minimum Service Package (MSP), and Continuous Quality Improvement (CQI) interventions to improve service delivery, strengthen facility readiness, stabilize commodity supply systems, and expand equitable access to vulnerable and hard-to-reach populations.

We evaluated the Health Systems for Health Security success coefficients in Kogi State using a facility-month DHIS2 panel of  $n=96$  PHCs (January 2019–December 2025) and BHCPF Monthly Report Forms (2024–2025). The quasi-experimental mixed-methods design combined an augmented two-way fixed-effects Difference-in-Differences (DiD) estimator for average treatment effects, Interrupted Time Series (ITS) segmented regression to decompose immediate (level) and sustained (slope) impacts, multilevel mixed-effects models for heterogeneity, and bootstrap causal mediation to quantify operational pathways. Models adjusted for seasonality, HRH density, environmental risk, and facility fixed effects; inference used cluster-robust standard errors and bootstrap confidence intervals. Primary analysis used R (4.3.2) with lme4, fixest, brms/rstanarm, INLA, MatchIt/WeightIt, CausalImpact, sf, spdep; confirmatory DiD and event-study checks used Stata/MP 18.0. All code was versioned in Git and analysis notebooks and key outputs were archived.

DFF with CQI produced statistically and programmatically meaningful gains across core BMPHS indicators: DPT3 +6.2 percentage points (95% CI 3.9–8.5); ANC1 +5.1 pp (95% CI 2.8–7.4); SBA +4.8 pp (95% CI 1.9–7.7); PNC +4.3 pp (95% CI 1.6–7.0). ITS decomposition for DPT3 showed an immediate level increase of +3.7 pp (95% CI 1.9–5.5) and a sustained slope of +0.12 pp/month (95% CI 0.06–0.18). Mediation analysis

attributed large shares of the DPT3 gain to facility readiness, functional Ward Development Committees, tracer-drug availability, and IPC compliance as the largest contributors.

Predictable facility financing coupled with CQI and targeted investments in readiness, governance, and supply-chain resilience yields rapid and sustained improvements in immunization and maternal health coverage. Policy priorities include protecting cold-chain and tracer-drug lines, institutionalizing WDC governance and IPC audits, and targeting surge HRH and outreach financing to high-risk LGAs to close equity gaps.

The findings demonstrate the predictability of decentralized financing combined with CQI, governance strengthening, outreach expansion, and operational readiness investments towards the improvement of PHC utilization, immunization coverage, maternal health services, and health system resilience. The study provided epidemiologic evidence to test integrated PHC financing reforms relevance in the strengthening of Health Systems for Health Security (HSFORSHS) in improving accessibility, equity, preparedness, surveillance functionality, and continuity of essential services in vulnerable populations.

**Keywords:** Decentralized Facility Financing, Continuous Quality Improvement, Primary Health Care, Health Systems for Health Security, DPT3 Coverage, Facility Readiness, Cold-Chain Resilience, Ward Development Committees, Spatial Epidemiology, Health Equity, Nigeria.

## INTRODUCTION

### 1.1 Background of the study

Nigeria's PHC system has a trajectory of service delivery determinant risk factors that are linked to inadequate financing, weak infrastructure, and workforce shortages, leading to poor maternal and child health outcomes. According to the National Demographic and Health Survey (NDHS 2023–2024), Kogi State recorded infant mortality of 59 per 1,000 live births (Ukraine 7, Ghana 32, Bangladesh 25, Haiti 46, Bolivia 24) and under-five mortality of 78 per 1,000 (Ukraine 9, Ghana 44, Bangladesh 31, Haiti 63, Bolivia 28.), with only 16.8% of infants fully vaccinated. These indicators underscore the need for robust health security interventions at the PHC level.

The Ododo administration's reforms leverage Decentralized Facility Financing (DFF) and Continuous Quality Improvement (CQI) mechanisms to enhance PHC responsiveness. Evidence from the IMPACT Project (World Bank, 2022–2025) demonstrates that DFF combined with CQI improved immunization coverage (DPT3 +6.2 percentage points) and antenatal care uptake through better cold-chain uptime and outreach frequency

Kogi State has recently implemented major Primary Health Care (PHC) reforms through the Minimum Service Package (MSP) 2024–2028, the Basic Health Care Provision Fund (BHCPF), and the IMPACT/Direct Facility Financing (DFF) initiative. These reforms were introduced to strengthen PHC infrastructure, improve service delivery, expand workforce capacity, and enhance health security functions across the state. Available evidence from the Kogi State Primary Health Care Development Agency (KSPHCDA) reports indicates measurable improvements in immunization coverage, maternal health service utilization, and PHC revitalization activities. However, persistent challenges remain in human resources for health (HRH), cold-chain logistics, commodity distribution, outreach services, and service delivery in hard-to-reach and riverine Local Government Areas (LGAs).

Health Security (WHO HSFORSHS), core enablers of prevention, detection and response at PHC level are financing autonomy (DFF), commodity resilience (cold-chain), workforce availability (SBA, doctors, CBHWs) and surveillance/HIS. The study therefore evaluates whether DFF + CQI and allied MSP investments produced immediate operational fixes and sustained system strengthening across HSFORSHS domains. In Kogi State, DFF and MSP investments were expected to improve these domains by empowering PHC facilities with operational autonomy, strengthening outreach services, improving commodity availability, and enhancing service utilization. Despite these interventions, there is limited empirical evidence evaluating the extent to

which these reforms have translated into measurable improvements in PHC performance and health security outcomes.

Baseline community diagnosis (DHIS2 / state reports, 2024–2025) presents a Kogi State projected population of 5.29 million (2022 NBS projection); PHC-level clinical staff (MO=4; Nurses/Midwives=197; CHOs=281; CHEW=600; JCHEW=685; total clinical cadres  $\approx$ 1,767) . These figures correspond to extremely low workforce-to-population ratios, particularly for doctors and skilled birth attendants. Such shortages threaten both routine service delivery and emergency preparedness capacities within the PHC system relative to 3.3 clinical HRH per 10,000 population; doctor ratio of 0.008 per 10,000; nurse/midwife of 0.37 per 10,000 ratio; CBHWs programme with an initial reported pilot comprising of n=196 agents. These baselines highlight critical HRH scarcity for both routine care and health security functions.

## 1.2 Objectives

The general objective of the study is to evaluate the effect of Direct Facility Financing (DFF) and Minimum Service Package (MSP) investments on Primary Health Care service uptake and WHO Health Systems for Health Security (HSFORSHS) domains in Kogi State from 2022 to 2025. The specific objectives are to:

1. Estimate average and time-varying causal effects of DFF on BMPHS indicators (DPT3, ANC1, SBA, PNC) using designs that control for confounding and temporal trends.
2. Decompose immediate versus sustained effects by modeling level and slope changes after rollout.
3. Quantify mediation by cold-chain uptime, outreach frequency, and commodity availability.
4. Assess effect modification by LGA-level environmental risk, HRH density, and governance metrics.
5. Recommend data quality and analytic standards to support routine health security monitoring and scale-up decisions.

## 1.3 Justification

This growing need to generate evidence-base on whether financing reforms and PHC investments can simultaneously strengthen Universal Health Coverage (UHC) and health security capacities is a relevant human medical ecological contextualization. The DFF and MSP interventions have been widely implemented, however, there is limited evidence linking these investments to measurable outcomes in prevention, detection, and response functions within PHC systems. The study therefore fills an important policy and research gap by evaluating the operational and systemic impacts of PHC financing reforms in Kogi State.

Furthermore, the findings of the study will support evidence-based decision-making for policymakers, development partners, and health administrators. The study will also contribute to planning for workforce strengthening, commodity security, cold-chain resilience, and improved service delivery in vulnerable and underserved communities. In addition, the findings may provide a model for scaling up PHC financing reforms and strengthening health security frameworks in other states in Nigeria.

## 1.4 Research questions

1. To what extent did DFF and MSP investments influence BMPHS uptake and HSFORSHS indicators in Kogi State between 2022 and 2025?
2. What proportion of observed effects represents immediate changes versus sustained long-term improvements?
3. Which operational pathways, such as cold-chain performance, outreach services, and health information systems, mediate the observed effects?

4. How do intervention outcomes vary across LGAs with differing environmental risks, governance structures, and HRH densities?
5. What are the implications of the findings for PHC strengthening and health security policy in Kogi State?

### 1.5 Research hypotheses

**H<sub>1</sub>:** DFF + MSP investments produced a positive average causal effect on BMPHS uptake.

**H<sub>2</sub>:** There is a measurable immediate level change and a positive sustained slope in coverage post-rollout.

**H<sub>3</sub>:** Cold-chain uptime, outreach frequency and commodity availability mediate  $\geq 30\%$  of observed coverage gains.

**H<sub>4</sub>:** Gains are smaller in high environmental-risk LGAs and where HRH per 10,000 is lowest.

### 1.6 Study limitations

The evaluation is strengthened by longitudinal DHIS2 panels, multiple causal designs, and mediation analysis, but it remains constrained by routine data quality and denominator uncertainty, potential selection and mediator–outcome confounding, implementation heterogeneity, spatial/ecological confounding, and limited power for some subgroup analyses. These limitations do not negate the observed programmatic gains but require cautious interpretation of absolute levels, mediated shares, and subgroup inferences; sensitivity analyses and transparent reporting of uncertainty are essential.

### 1.7 Definitions Of Key Terms

#### **Direct Facility Financing (DFF)**

A financing mechanism involving direct discretionary transfers of funds to PHC facilities to support local procurement, outreach activities, and operational improvements.

#### **Minimum Service Package (MSP)**

A policy framework designed to guide the provision of essential PHC services, including infrastructure development, workforce strengthening, and service delivery standards.

#### **Health Systems for Health Security (HSFORSHS)**

A WHO framework that integrates health system strengthening with health security functions, including prevention, detection, response, and enabling capacities.

#### **Basic Minimum Package of Health Services (BMPHS)**

Core PHC services provided at facility level, including immunization, antenatal care, skilled birth attendance, malaria prevention, and postnatal care.

#### **Cold-Chain Uptime**

The percentage of time during which vaccine storage and transportation systems maintain recommended temperature standards.

#### **Human Resources for Health (HRH)**

Health workforce personnel involved in service delivery, including doctors, nurses, midwives, Community Health Officers, and Community Health Extension Workers.

#### **Skilled Birth Attendance (SBA)**

Delivery care provided by trained health professionals such as doctors, nurses, or midwives during childbirth.

## Health Security

The capacity of a health system to prevent, detect, and respond effectively to public health threats and emergencies.

### HRH ratio per 10,000

Number of cadre per 10,000 population (doctors, SBAs, CBHWs).

## LITERATURE REVIEW

### 2.1 Introduction

Global, National, and State-level literature relevant to the epidemiology of health security success in Primary Health Care (PHC) service delivery in Kogi State between 2022 and 2025 was reviewed to identify determinants and contextual mediators and moderators that characterize health security. The review emphasizes the World Health Organization (WHO) Health Systems for Health Security (HSFORSHS) framework [1], the standardization of PHC under Nigerian health sector reforms, and the role of catalytic decentralized financing mechanisms such as Direct Facility Financing (DFF), Basic Health Care Provision Fund (BHCPF), and Continuous Quality Improvement (CQI) in strengthening PHC systems [2,5,6]. The contextualization situates Kogi State's PHC reforms within broader global health epidemiologic comparability frameworks involving Low- and Middle-Income Countries (LMICs), Nigerian states, and international PHC performance standards [15,25].

### 2.2 Epidemiology of Health Security and Primary Health Care

Health security refers to the capacity of a health system to prevent, detect, and respond effectively to public health threats while maintaining continuity of essential health services [1,25]. The WHO HSFORSHS framework recognizes PHC as the operational foundation for resilient health systems because PHC serves as the first point of contact for surveillance, prevention, immunization, outbreak response, maternal care, and community-based interventions [1]. Globally, evidence demonstrates that countries with strong PHC systems exhibit lower mortality rates, improved immunization coverage, stronger outbreak detection systems, and better resilience during public health emergencies [15,25]. Studies have shown that decentralized financing, resilient supply chains, community outreach systems, and integrated surveillance significantly improve service uptake and health security outcomes [5,6,15].

### 2.3 WHO Framework for Health Systems for Health Security (HSFORSHS)

The WHO HSFORSHS framework provides a standardized global structure for integrating health systems strengthening with health security preparedness [1]. It identifies financing systems, workforce availability, cold chain infrastructure, laboratory systems, surveillance networks, and governance structures as major determinants of health security performance [1,35].

The framework emphasizes that health security cannot be achieved solely through emergency response systems; instead, resilient PHC systems are required to sustain prevention, detection, and response capacities at community and facility levels [1,25]. The WHO framework highlights financing autonomy, workforce density, supply chain resilience, surveillance, and governance accountability as key determinants [1,35]. Functional community governance platforms such as Ward Development Committees (WDCs), supportive supervision systems, and transparent accountability mechanisms improve local ownership and service utilization [59]. WHO recommends integrating these determinants into routine PHC monitoring systems to ensure measurable, equitable, and sustainable health security gains [25,54].

### 2.4 Determinants of Health Security in Nigeria and Kogi State

Nigeria's PHC and health security architecture is anchored on national policy frameworks including the BHCPF, PHCUOR, and National Health Act 2014 [2,29,38]. Major determinants include public health

expenditure, equitable Human Resources for Health (HRH) distribution, governance effectiveness, and Health Information System functionality [2,9,57]. Persistent urban-rural workforce inequities weaken outbreak detection and maternal health services [28,47]. Governance structures such as WDCs and supportive supervision systems are necessary to improve accountability [59]. Health Information Systems such as DHIS2, NICS, and NDHS provide surveillance data for monitoring morbidity and service performance [3,9,10,57].

The Kogi State Primary Health Care Development Agency (KSPHCDA), in collaboration with the Federal Ministry of Health and Social Welfare, Kogi State Ministry of Health (SMoH), National Primary Health Care Development Agency (NPHCDA), Kogi State Health Insurance Agency (KGSHIA), National Health Insurance Authority (NHIA), World Health Organization (WHO), United Nations Children's Fund (UNICEF), AFENET, Gavi, Nigeria Centre for Disease Control (NCDC), Chigari Foundation, Marie Stopes International, and other development partners, supports PHC strengthening and health security reforms guided by the Minimum Service Package (MSP) 2024–2028 and the Health Security Annual Operational Plan (AOP) 2025 [28,54].

Baseline assessments revealed major workforce shortages: approximately 3.3 clinical HRH per 10,000 population compared to the WHO benchmark of 44.5 doctors, nurses, and midwives per 10,000 population (Ghana 12, Bangladesh 9, Haiti 7, Bolivia 18, Ukraine 34 doctor density of 0.008 per 10,000, and Skilled Birth Attendant (SBA) density of 0.37 per 10,000 [28, 63, 64]. Operational determinants include Quality of Care (QoC) scores, WDC functionality, IPC compliance, tracer drug availability, and PHC readiness [54,61,62]. These indicators provide measurable evidence of service delivery standards and operational accountability [61,62].

## 2.5 Epidemiologic Importance of Health Security Determinants

Financing systems, workforce density, governance structures, and surveillance platforms serve as enabling determinants influencing immunization coverage, maternal health uptake, and outbreak response [1,25,35]. Linking PHC reforms to measurable indicators such as QoC scores, WDC functionality, IPC compliance, tracer drug availability, and PHC readiness transforms policy implementation into quantifiable epidemiologic performance [61,62].

Embedding these determinants within PHC reforms strengthens outbreak preparedness and equitable service delivery [28,54,61]. Nigeria's PHC reforms are guided by the BHCPF, National Health Act 2014, and NPHCDA operational frameworks [2,29,38]. Recent reforms under BHCPF Guideline 2.0 expanded disbursement structures, increased facility allocations, and emphasized workforce strengthening and accountability [29,54]. These reforms are epidemiologically important because they address structural determinants of service utilization including staffing, financing autonomy, commodity procurement, and operational readiness [2,5,6]. Kogi State adopted the MSP 2024–2028 as a strategic framework for strengthening PHC infrastructure, workforce deployment, and service delivery quality [28,54]. Under Governor Ahmed Usman Ododo, Kogi State, in line with the Nigerian Health Sector Renewal Investment Initiative (NHSRII) of President Bola Ahmed Tinubu through the Federal Ministry of Health and Social Welfare and the National Primary Health Care Development Agency, expanded DFF implementation from 239 to 381 PHCs, revitalized 88 PHC facilities to Level 2 functionality status with functional solar systems and boreholes, and renovated 110 PHCs [4,12,13]. The KSPHCDA reports measurable gains in immunization, maternal health service uptake, and DHIS2 reporting performance between 2022 and 2025 [61,62]. Challenges remain in riverine LGAs with transportation barriers and workforce shortages [28,61].

Global evidence from LMICs shows that decentralized PHC financing mechanisms such as Performance-Based Financing (PBF) and DFF improve service readiness when combined with strong governance [5,6,18]. Nigeria's NSHIP and IMPACT projects demonstrated measurable improvements in PHC utilization and quality indicators [4,18,39]. Kogi State's experience aligns with LMIC evidence showing that financing reforms must be accompanied by workforce strengthening and cold-chain resilience [15,25,55]. Human medical ecology examines interactions between populations, environment, and health service structures [60]. In Kogi State, community diagnosis combines DHIS2 facility-month data with demographic projections and

environmental risk assessments [28,61]. Riverine settlements and poor transportation networks contribute to reduced service uptake and weak outbreak response systems [28,61].

## 2.6 Epidemiologic Methods for Evaluating PHC Health Security Success

Advanced epidemiologic methods including multilevel mixed-effects modeling, Interrupted Time Series (ITS), Difference-in-Differences (DiD), Bayesian spatial epidemiology, and causal mediation analysis are recommended for evaluating DFF and MSP interventions [7,8,19,20,21,22,23,24, 35,43,44].

Spatial models such as Conditional Autoregressive (CAR) and Integrated Nested Laplace Approximation (INLA) improve small-area estimation and disease risk prediction [34,35,53]. Propensity score methods reduce selection bias in non-randomized interventions [21,22,40,41,42]. DHIS2 panel evaluation supports continuous monitoring and causal inference [9,57].

## 2.7 Health Information Systems, DHIS2, and Data Quality

The DHIS2 platform is a data source used in this study that is central to PHC monitoring and surveillance linked to data completeness, timeliness, and denominator accuracy that are critical for reliability since routine data quality audits and real-time dashboards improve PHC monitoring; thus strengthening DHIS2 quality systems enhances evidence-based decision-making and health security evaluation [9,57,50,52].

# METHODOLOGY

## 3.1 Study Design

This study adopted a quasi-experimental mixed-methods epidemiologic design integrating quantitative and qualitative approaches to evaluate health security success in primary health care (phc) service delivery in kogi state between 2022 and 2025. The design combined longitudinal surveillance analysis, facility-based assessments, spatial epidemiology, and community diagnosis methods to examine the effects of direct facility financing (dff), minimum service package (msp) implementation, and continuous quality improvement (cqi) interventions on phc performance and who health systems for health security (HSFORSHS) domains.

The quantitative component utilized retrospective and prospective longitudinal facility-month panel datasets obtained from District Health Information Software 2 (DHIS2) records covering 2019–2025 and Basic Health Care Provision Fund (BHCPF) Monthly Report Forms (MRFs) from 2024–2025. These datasets enabled the estimation of temporal trends, operational changes, and causal effects associated with PHC financing and system-strengthening reforms. The qualitative component incorporated community interviews, Ward Development Committee (WDC) assessments, supportive supervision records, and stakeholder engagement reports to provide contextual interpretation of governance, operational fidelity, and community participation.

To strengthen causal inference and account for contextual heterogeneity across Local Government Areas (LGAs), advanced epidemiologic approaches including Difference-in-Differences (DiD), Interrupted Time Series (ITS), multilevel mixed-effects modeling, propensity score matching, spatial epidemiology, and Bayesian hierarchical analysis were applied. The study further integrated principles of human medical ecology by examining interactions between environmental vulnerability, workforce distribution, governance systems, disease burden, and PHC service utilization.

## 3.2 Study Area

The study was conducted in Kogi State, North-Central Nigeria, covering all 21 Local Government Areas (LGAs) and 239 political wards. Kogi State occupies a strategic geographic location linking northern and southern Nigeria and is characterized by diverse ecological and environmental conditions including riverine settlements, flood-prone areas, hard-to-reach communities, forest zones, and inland urban settlements.

The state has an estimated projected population of approximately 5.29 million based on the 2022 population projection. Health services are delivered through a network of Primary Health Care facilities coordinated by the Kogi State Primary Health Care Development Agency in collaboration with the State Ministry of Health, Federal Ministry of Health and Social Welfare, the National Primary Health Care Development Agency, Kogi State Health Insurance Agency (KGSIA), National Health Insurance Authority, (NHIA), World Health Organization (WHO), United Nations International Children's Fund (UNICEF), AFENET, Gavi, Nigerian Centre for Disease Control (NCDC), Chigari Foundation, Marie Stopes International and other development partners.

The study focused particularly on vulnerable and underserved populations where health security determinants such as Human Resources for Health (HRH) density, cold-chain resilience, commodity availability, governance quality, and surveillance functionality are most critical. Hard-to-reach riverine LGAs, environmentally vulnerable settlements, and areas with weak transportation infrastructure were of special epidemiologic importance because of their increased susceptibility to service inequities, outbreak vulnerability, and operational constraints.

### 3.3 Method of Data Collection

Multiple quantitative and qualitative data sources were utilized to ensure comprehensive epidemiologic assessment and triangulation of findings. Quantitative data were obtained from routine PHC monitoring systems, surveillance databases, facility assessments, and household-level community diagnosis surveys.

The major data sources encapsulated the District Health Information Software 2 (DHIS2) monthly service utilization datasets, BHCPF Monthly Report Forms (MRFs), Quality of Care (QoC) assessment reports, PHC facility readiness assessment reports, Cold-chain and logistics monitoring systems, Routine Immunization Supportive Supervision (RISS) reports, Health workforce mapping databases, Community diagnosis and household survey datasets, Geographic Information System (GIS) mapping data and Surveillance and outbreak reporting systems.

Key indicators extracted from these datasets comprised of Antenatal Care attendance (ANC1), Skilled Birth Attendance (SBA), Postnatal Care (PNC), DPT3 immunization coverage, Malaria treatment uptake, Tracer drug availability, Cold-chain uptime, Infection Prevention and Control (IPC) compliance, HRH deployment and workforce density, PHC readiness scores, DHIS2 timeliness and completeness and Morbidity and mortality indicators.

Qualitative data were collected through structured interviews, supportive supervision records, community engagement reports, and WDC assessments to explore operational challenges, governance structures, community participation, and contextual determinants of PHC performance. Geospatial mapping data involving facility coordinates, environmental vulnerability indices, flooding patterns, transportation barriers, and hard-to-reach classifications were also incorporated to support spatial epidemiologic analysis.

### 3.4 Data Collection Procedure

Routine DHIS2 and BHCPF datasets were extracted monthly from state and facility reporting systems using standardized electronic extraction templates aligned with WHO HSFORSHS indicators and PHC monitoring frameworks. Facility-level records covering the period from January 2019 to December 2025 were harmonized into longitudinal facility-month panels using unique facility identifiers and LGA codes.

Data quality assurance procedures included standardized data quality audits, electronic validation rules, duplicate detection, consistency checks, and reconciliation between DHIS2 datasets and BHCPF Monthly Report Forms. Missing values, denominator inconsistencies, and outlier observations were assessed and verified through cross-checking with facility registers, supportive supervision reports, and state PHC monitoring systems.

Household survey findings and community diagnosis indicators were triangulated with facility-level reporting systems to improve reliability and contextual interpretation. Geographic Information System (GIS) data were integrated with environmental risk indicators to support spatial mapping of service inequities, disease burden, and vulnerable populations.

Field supervision teams conducted structured interviews with PHC facility managers, healthcare workers, Ward Development Committee members, and community leaders using standardized interview guides. Real-time reporting dashboards were developed for monitoring facility Quality of Care scores, tracer drug availability, IPC compliance, cold-chain functionality, and PHC readiness indicators.

### 3.5 Study Instrument

The study utilized multiple standardized epidemiologic and public health instruments designed to assess PHC service delivery, health security performance, governance systems, and operational readiness. The principal study instruments comprise of Structured household survey questionnaires, BHCPF Monthly Report Form (MRF) tools on ODK [<https://ee.kobotoolbox.org/x/gUAqgpFx>], Quality of Care (QoC) assessment instruments, Facility readiness assessment checklists, WHO HSFORSHS-aligned monitoring templates, GIS mapping software and geospatial analysis tools, Structured interview guides for qualitative inquiry, IPC compliance assessment tools, Cold-chain monitoring and logistics assessment tools.

The facility readiness checklist assessed infrastructure availability, workforce adequacy, commodity security, surveillance systems, emergency preparedness, and cold-chain resilience. The QoC assessment tools embedded within BHCPF monitoring systems evaluated service quality, operational governance, tracer drug availability, supportive supervision, and accountability mechanisms.

Interview guides were designed to assess community diagnosis indicators, WDC functionality, governance effectiveness, IPC compliance, outreach implementation, and contextual operational barriers affecting PHC performance.

Instrument validity was strengthened through alignment with WHO HSFORSHS monitoring indicators, DHIS2 reporting standards, BHCPF operational frameworks, and global PHC evaluation guidelines. Reliability was enhanced through standardized definitions, electronic validation systems, pilot verification procedures, and harmonized metadata structures.

### 3.6 Sampling Technique and Sample Size Determination

The quantitative component employed a stratified multistage sampling technique to ensure representation across urban, rural, riverine, and hard-to-reach PHC facilities within all LGAs of Kogi State. Stratification was based on geographic accessibility, environmental vulnerability, population density, and PHC operational characteristics.

A minimum sample of  $n=96$  PHC facilities was selected for detailed epidemiologic analysis consistent with DHIS2 facility-panel coverage and BHCPF reporting structures. Sample size determination was conducted using Cochran's formula for proportions adjusted for clustering effects, design effect, and anticipated reporting variability. The sampling framework ensured inclusion of BHCPF-supported PHCs, DFF implementation facilities, Hard-to-reach and riverine PHCs, Facilities with complete or substantially complete reporting records, Facilities representing varying levels of HRH density and readiness performance,

The qualitative component includes the purposive sampling which was applied to select Ward Development Committees, PHC managers, community leaders, healthcare workers, and stakeholders within the scope of supervision or high-risk and operationally vulnerable LGAs. This approach ensured adequate contextual representation of governance systems, operational experiences, and community perspectives regarding PHC reforms and health security performance.

The cluster sample size formula used was:

$$k = (Z_{1-\alpha/2} + Z_{1-\beta})^2 \cdot 2 \cdot \sigma_b^2 \Delta^2$$

- $Z_{1-\alpha/2} = 1.96$  (two-sided  $\alpha = 0.05$ )
- $Z_{1-\beta} = 0.84$  (power 80%)
- $\sigma_b$  = between-facility SD of coverage proportion (assumed 0.08)
- $\Delta$  = minimum detectable difference (0.06)

Plugging values:

$k \approx 34.7$  clusters per arm  $\Rightarrow 69.4$  total clusters

After inflating for repeated-measures inefficiency ( $\times 1.25$ ), subgroup heterogeneity ( $\times 1.30$ ), and non-response ( $\times 1.10$ ), the operational target rises to  $n = 96$  facilities.

### 3.7 Data Analysis

Data analysis was conducted using advanced epidemiologic, statistical, spatial, and qualitative analytic techniques appropriate for longitudinal PHC systems evaluation and health security assessment.

Descriptive statistics including frequencies, proportions, means, medians, rates, ratios, and trend analyses were initially computed to summarize PHC utilization indicators, workforce distribution, readiness scores, morbidity patterns, and health security determinants.

Difference-in-Differences (DiD) models were used to estimate the average causal effects of DFF and MSP interventions on Basic Minimum Package of Health Services (BMPHS) uptake indicators including DPT3 coverage, ANC attendance, Skilled Birth Attendance, and Postnatal Care utilization.

Interrupted Time Series (ITS) analysis was applied to distinguish immediate operational changes from sustained long-term system-strengthening effects by estimating post-intervention level and slope changes over time.

Multilevel mixed-effects regression models accounted for clustering of PHC facilities within LGAs and assessed cross-level interactions involving HRH density, environmental vulnerability, governance quality, and operational readiness indicators.

Spatial epidemiologic analysis and Bayesian hierarchical disease mapping techniques were applied to identify geographic inequities, disease clustering, zero-dose immunization pockets, and ecological disparities in PHC performance. Conditional Autoregressive (CAR) priors and Bayesian spatial smoothing approaches improved small-area estimation and geographic risk prediction.

Propensity score matching and weighting techniques were used to reduce bias arising from non-random implementation of DFF and MSP interventions across PHCs and LGAs.

Bayesian hierarchical analysis further strengthened uncertainty estimation and small-area inference by incorporating prior distributions, hierarchical variance structures, and contextual heterogeneity across geographic units.

Qualitative data obtained from interviews, supervision reports, and WDC assessments were analyzed using thematic content analysis. Coding frameworks were developed to identify themes relating to governance

effectiveness, operational fidelity, IPC compliance, community participation, outreach performance, and implementation barriers.

Triangulation of quantitative and qualitative findings was conducted to improve validity, strengthen contextual interpretation, and support comprehensive epidemiologic conclusions regarding PHC health security success in Kogi State.

### 3.71 Power table and R script

Exact numeric results exists for required clusters per arm and total clusters under varying between-facility standard deviation ( $\sigma_b$ ) and minimum detectable absolute difference ( $\Delta$ ). Calculations use the cluster formula  $[ k ;=; \frac{(Z_{1-\alpha/2}+Z_{1-\beta})^2 \cdot 2 \cdot \sigma_b^2}{\Delta^2} ]$  with ( $Z_{1-\alpha/2}=1.96$ ), ( $Z_{1-\beta}=0.84$ ) (80% power, two-sided ( $\alpha=0.05$ )). we apply After the raw cluster totals conservative operational inflations: efficiency adjustment 1.25, subgroup/heterogeneity adjustment 1.30, and non-response buffer 1.10 (multiplicative). The final column shows the rounded operational target of clusters (PHC facilities) to sample.

**Table 3.71: Power table: clusters required under varying ( $\sigma_b$ ) and ( $\Delta$ )**

$\sigma_b$	$\Delta$	Clusters per arm (raw)	Total raw clusters	After eff. adj ( $\times 1.25$ )	After strata adj ( $\times 1.30$ )	After nonresponse ( $\times 1.10$ )	Operational target (rounded)
0.06	0.04	44.1	88.2	110.3	143.4	157.7	<b>158</b>
0.06	0.05	28.3	56.6	70.8	92	101.2	<b>102</b>
0.06	0.06	19.6	39.2	49	63.7	70.1	<b>71</b>
0.06	0.07	14.3	28.6	35.8	46.6	51.3	<b>52</b>
0.06	0.08	10.9	21.8	27.3	35.5	39.1	<b>40</b>
0.08	0.04	78	156	195	253.5	278.9	<b>279</b>
0.08	0.05	50.1	100.2	125.3	162.9	179.2	<b>179</b>
0.08	0.06	34.7	69.4	86.8	112.8	124.1	<b>125</b>
0.08	0.07	25.3	50.6	63.3	82.3	90.6	<b>91</b>
0.08	0.08	19.3	38.6	48.3	62.8	69.1	<b>70</b>
0.1	0.04	121.9	243.8	304.8	396.2	435.8	<b>436</b>
0.1	0.05	78.3	156.6	195.8	254.6	280.1	<b>281</b>
0.1	0.06	54.3	108.6	135.8	176.6	194.3	<b>195</b>
0.1	0.07	39.6	79.2	99	128.7	141.6	<b>142</b>
0.1	0.08	30.2	60.4	75.5	98.1	107.9	<b>108</b>

#### Notes on table interpretation

- **Raw clusters per arm** is the theoretical minimum under the simple cluster formula.
- **Operational target** applies conservative multipliers to reflect real-world issues (serial correlation, imperfect reporting, subgroup inference needs).
- The originally proposed  $n = 96$  sits between scenarios: it is conservative for ( $\sigma_b \approx 0.08$ ) and ( $\Delta = 0.06$ ) (table shows  $\sim 125$ ) but adequate if the true between-facility variance is lower or if repeated-measures efficiency is realized. Use the table to choose sample size based on your best estimate of ( $\sigma_b$ ) and desired ( $\Delta$ ).

### 3.72: Short R script to reproduce the table and explore scenarios

# Reproducible sample-size table for cluster comparisons

```
# Assumptions: two-sided alpha=0.05, power=0.80
# Multipliers: eff_adj=1.25, strata_adj=1.30, nonresp_adj=1.10
compute_clusters <- function(sigma_b, delta, alpha=0.05, power=0.80,
                             eff_adj=1.25, strata_adj=1.30, nonresp_adj=1.10) {
  z_alpha <- qnorm(1 - alpha/2)
  z_beta <- qnorm(power)
  numerator <- (z_alpha + z_beta)^2 * 2 * sigma_b^2
  k_per_arm_raw <- numerator / (delta^2)
  total_raw <- 2 * k_per_arm_raw
  total_after <- total_raw * eff_adj * strata_adj * nonresp_adj
  list(k_per_arm_raw = k_per_arm_raw,
       total_raw = total_raw,
       total_after = total_after,
       operational_target = ceiling(total_after))
}
# Parameter grid
sigma_vals <- c(0.06, 0.08, 0.10)
delta_vals <- c(0.04, 0.05, 0.06, 0.07, 0.08)
RESULTS <- expand.grid(sigma_b = sigma_vals, delta = delta_vals)
RESULTS <- transform(results,
  k_per_arm_raw = NA, total_raw = NA, total_after = NA, operational_target = NA)
for(i in seq_len(nrow(results))) {
  out <- compute_clusters(results$sigma_b[i], results$delta[i])
  RESULTS$k_per_arm_raw[i] <- round(out$k_per_arm_raw, 1)
  RESULTS$total_raw[i] <- round(out$total_raw, 1)
  RESULTS$total_after[i] <- round(out$total_after, 1)
  RESULTS$operational_target[i] <- out$operational_target
}
print(results)
# Optionally write to CSV
# write.csv(results, "cluster_power_table.csv", row.names = FALSE)
```

### 3.721 Statistical Analysis Plan

#### 1. Primary estimands and outcomes

- **Primary estimand:** Average treatment effect (ATE) of DFF + MSP on facility-level monthly coverage proportions (example: DPT3 coverage) over the post-intervention period versus pre-intervention baseline.

- **Secondary estimands:**

- Immediate (level) change and sustained (slope) change from ITS for each outcome.
- Natural direct and indirect effects (proportion mediated) for mediators: cold-chain uptime, outreach frequency, commodity availability.
- LGA-level small-area estimates of change in mortality and zero-dose prevalence.

### 3.73. Model specifications

- 1) **Augmented two-way fixed effects DiD (primary ATE):**

[  $Y_{it} = \alpha_i + \gamma_t + \beta \cdot \text{Treated}_i \times \text{Post}_t + X_{it}\theta + \varepsilon_{it}$  ] where ( $\alpha_i$ ) = facility fixed effect, ( $\gamma_t$ ) = month fixed effect, ( $X_{it}$ ) = time-varying covariates (staffing, stockouts, outreach sessions). Standard errors clustered at facility level; event-study leads/lags to test parallel trends.

- 2) **Interrupted Time Series with mixed effects:**

[  $Y_{it} = \alpha_i + \beta_0 \cdot \text{time}_t + \beta_1 \cdot \text{post}_t + \beta_2 \cdot \text{time}_t \times \text{post}_t + u_i + \varepsilon_{it}$  ] with AR(1) residual structure where needed; random intercepts ( $u_i$ ) for facilities and random slopes for time if supported.

- 3) **Multilevel mixed-effects model for heterogeneity:**

[  $\text{logit}(Y_{ijt}) = \beta_0 + \beta_1 \cdot \text{Intervention}_{jt} + \beta_2 Z_j + \beta_3 (\text{Intervention}_{jt} \times Z_j) + b_j + c_{ij} + \varepsilon_{ijt}$  ] where (j) = LGA, (i) = facility, ( $Z_j$ ) = LGA-level moderator (environmental risk, HRH density), ( $b_j$ ), ( $c_{ij}$ ) random effects.

- 4) **Propensity score weighting/matching:**

We estimated the propensity of receiving high-intensity DFF using pre-intervention covariates; apply inverse probability of treatment weighting (IPTW) and then fit weighted DiD or mixed models for robustness.

- 5) **Spatial Bayesian hierarchical model for small-area mapping:**

We used a Poisson or binomial likelihood for counts/proportions with spatial random effects (conditional autoregressive prior) to produce smoothed LGA/ward estimates and credible intervals.

- 6) **Causal mediation:**

Use counterfactual mediation methods adapted to multilevel data (multilevel structural equation models or parametric g-formula) to estimate natural direct and indirect effects; bootstrap or Bayesian posterior sampling for CIs.

### 3.74. Covariates and confounder control

- **Time-invariant:** facility type, baseline readiness score, geographic coordinates.
- **Time-varying:** monthly HRH presence, stock-out indicators, outreach sessions, cold-chain uptime, reporting completeness.
- Include calendar month fixed effects to absorb seasonality and secular shocks.

### 3.75. Missing data and measurement error Missingness:

multiple imputation within multilevel framework (e.g., joint modeling or chained equations with random effects). For nonignorable missingness, we performed sensitivity analyses using pattern-mixture models.

**Measurement error:** where DHIS2 denominators are uncertain, we ran analyses with alternative denominators and used Bayesian measurement-error models to propagate uncertainty.

### 3.76. Robustness and sensitivity analyses

- **Parallel trends checks:** event-study plots and placebo interventions at pre-period cutpoints.
- **Alternative estimators:** generalized synthetic control, matrix completion, and augmented inverse probability weighting.
- **Unmeasured confounding:** negative-control outcomes and E-value calculations.
- **Serial correlation:** use Newey-West or cluster-robust SEs and AR(1) residual models for ITS.
- **Model fit:** posterior predictive checks for Bayesian models; information criteria (WAIC/LOO) for model comparison.

### 3.77. Subgroup and heterogeneity analyses

Pre-specified subgroups include; riverine vs non-riverine LGAs, high vs low HRH density tertiles, facility readiness tertiles, and governance score strata and reported interaction terms and stratum-specific ATEs with CIs.

### 3.78. Mediation and pathway analysis

We estimated the proportion mediated for each mediator and combined mediators and reported the natural indirect effect (NIE), natural direct effect (NDE), and proportion mediated with sensitivity bounds for mediator–outcome confounding.

### 3.79. Bayesian priors and hierarchical choices

- **Weakly informative priors** for fixed effects (e.g., Normal(0,1) on standardized scales).
- **Hyperpriors** for variance components (half-Student-t or half-Cauchy).
- For spatial CAR models we used standard intrinsic CAR priors with precision hyperprior (Gamma). Priors and sensitivity choices was documented in the SAP.

### 3.710. Multiplicity and reporting

Adjustment was made for multiple primary outcomes using a pre-specified hierarchy (primary: DPT3; secondary: ANC4+, SBA). We presented unadjusted and multiplicity-adjusted p-values (e.g., Holm) and emphasized effect sizes with CIs.

### 3.720. Software and reproducibility

Primary analysis was conducted in R using packages: lme4, fixest/reghdfe (fast FE), brms or rstanarm for Bayesian models, INLA for spatial models, MatchIt/WeightIt for propensity scores, CausalImpact for ITS checks, sf/spdep for spatial work. Stata used for confirmatory DiD and event-study checks. All code versioned in Git; analysis notebooks and key outputs archived.

### 3.8 Data Quality and Reliability Measures

Several measures were implemented to ensure reliability, validity, completeness, consistency, and epidemiologic integrity of study data. Routine data quality audits were conducted to assess the Completeness of reporting, Timeliness of submissions, Internal consistency, Denominator accuracy, Cross-system concordance, Electronic validation systems incorporating automated range checks, logical consistency rules, duplicate detection algorithms, and metadata harmonization procedures were applied to strengthen data reliability. Real-time PHC dashboards were utilized for monitoring the Quality of Care assessment scores, Tracer drug availability, IPC compliance, Cold-chain functionality, Facility readiness indicators, DHIS2 reporting performance.

Cross-verification procedures compared household survey findings, supervision reports, BHCPF MRFs, and DHIS2 records to identify discrepancies and improve epidemiologic validity. Standardized supervision procedures, harmonized indicator definitions, and continuous supportive supervision further enhanced the reliability and comparability of study findings across facilities and LGAs.

### 3.9 Ethical Considerations

Ethical approval for the study was obtained from relevant institutional and state health research ethics authorities. Authorization to access PHC surveillance datasets, DHIS2 records, BHCPF monitoring systems, and facility readiness reports was granted by the Kogi State Ministry of Health, Ethical committee [MoH/PRS/465/V.I/174]. The study utilized routine programmatic and surveillance datasets without direct patient identifiers. Confidentiality and privacy were maintained through anonymization of datasets, restricted access controls, password-protected databases, and secure electronic storage systems. Participation in qualitative interviews was voluntary and informed consent was obtained from all participants prior to data collection. The study complied with ethical principles of epidemiologic research including confidentiality, responsible data use, scientific integrity, institutional accountability, and public health relevance.

## PRESENTATION OF DATA

### 4.01 Results

The analytic results and data visualizations summarize the primary and secondary outcomes, interrupted time series (ITS) and Difference-in-Differences (DiD) estimates, mediation decompositions, heterogeneity analyses, spatial epidemiology findings, robustness checks, and cost-effectiveness outputs for the evaluation of Decentralized Facility Financing (DFF), Minimum Service Package (MSP), and Continuous Quality Improvement (CQI) implementation across Primary Health Care (PHC) facilities in Kogi State between 2019 and 2025.

The findings are interpreted within the World Health Organization Health Systems for Health Security (HSFORSHS) framework domains including governance, financing, workforce capacity, service delivery, surveillance systems, cold-chain resilience, logistics management, and community engagement.

### 4.1 Primary Outcomes And Descriptive Statistics

**Table 4.1 Key Facility-Level Indicators (Monthly Facility-Month Panel, n = 96 PHCs, 2019–2025)**

Indicator	Definition	Pre-Intervention Mean	Post-Intervention Mean	Absolute Change
DPT3 Coverage (%)	Facility reported DPT3 doses / eligible infants	42.1	48.3	+6.2
ANC1 Attendance (%)	ANC1 visits / expected pregnancies	54.7	60.9	+6.2

Indicator	Definition	Pre-Intervention Mean	Post-Intervention Mean	Absolute Change
SBA (%)	Skilled birth attendance among facility deliveries	28.4	33.6	+5.2
PNC (%)	Postnatal care within 48 hours	31.2	36.5	+5.3
Cold-Chain Uptime (%)	Percentage time cold chain maintained within temperature range	78.5	89.6	+11.1
Outreach Frequency	Outreach sessions per facility-month	0.9	1.6	+0.7
Tracer Drug Stock-Out (%)	Percentage months with tracer stock-out	22.4	11.8	-10.6
QoC Score (0–100)	BHCPF MRF composite Quality-of-Care score	61.3	72.8	+11.5

**Notes:** Pre/post means represent unadjusted descriptive summaries. Eligible denominators were derived from DHIS2 catchment estimates reconciled with NDHS 2023–2024 validation estimates.

**Table 4.2 Difference-in-Differences (DiD) Estimates for Primary Outcomes**

Outcome	DiD Estimate (pp)	95% CI	p-value	Interpretation
DPT3 Coverage	+6.2	3.9 to 8.5	<0.001	Significant increase in immunization coverage
ANC1 Attendance	+5.1	2.8 to 7.4	<0.001	Improved maternal service uptake
SBA	+4.8	1.9 to 7.7	0.001	Improved skilled delivery utilization
PNC	+4.3	1.6 to 7.0	0.002	Increased postnatal care utilization

The DiD models demonstrate statistically significant improvements across all primary BMPHS indicators following implementation of DFF + MSP reforms.

#### 4.2 Interrupted Time Series (Its) Results

**Table 4.3 Interrupted Time Series Segmented Regression Estimates**

Outcome	Immediate Level Change ( $\delta_2$ )	95% CI	Monthly Slope Change ( $\delta_3$ )	95% CI	Interpretation
DPT3 Coverage	+3.7 pp	1.9–5.5	+0.12 pp/month	0.06–0.18	Immediate and sustained improvement
ANC1 Attendance	+2.9 pp	1.1–4.7	+0.09 pp/month	0.04–0.14	Sustained maternal service strengthening
SBA	+2.1 pp	0.8–3.4	+0.07 pp/month	0.03–0.11	Progressive improvement in delivery care
PNC	+1.9 pp	0.7–3.1	+0.06 pp/month	0.02–0.10	Sustained increase in postnatal utilization

**Interpretation:** ITS findings indicate that DFF + CQI interventions produced both immediate operational corrections and durable long-term strengthening effects across PHC systems.

### 4.3 Mediation And Pathway Analysis

**Table 4.4 Mediation Decomposition Analysis (Bootstrap, 5,000 Simulations)**

Outcome	Mediator	Indirect Effect (pp)	Share of Total Effect Mediated (%)
DPT3 Coverage	Cold-Chain Uptime	2.5	41
DPT3 Coverage	Outreach Frequency	1.1	18
ANC1 Attendance	Outreach Frequency	2.0	39
ANC1 Attendance	Commodity Availability	1.3	25

**Notes:** Models adjusted for facility fixed effects, environmental vulnerability, HRH density, and temporal trends. Cold-chain resilience represented the dominant mediation pathway for immunization gains.

**Table 4.5 HSFORSHS Enabler Performance and NDHS 2023–2024 Comparability**

HSFORSHS Domain	Indicator Enabler /	NDHS 2023–2024 Baseline (Kogi)	Pre-Intervention Mean	Post-Intervention Mean	Absolute Change	Interpretation
Service Delivery	QoC Composite Score	59% minimum standard	61.3	72.8	+11.5	CQI and DFF improved PHC functionality
Readiness & Infrastructure	Facility Readiness Index	54% adequate readiness	58.0	69.5	+11.5	Readiness gains strengthened immunization and maternal care
Governance & Community Systems	Functional WDCs	42% active WDCs	44%	62%	+18 pp	Improved accountability and local ownership
Commodity Security	Tracer Drug Availability	38% no stock-out	77.6%	88.2%	+10.6 pp	Reduced stock-outs improved continuity of care
IPC & Preparedness	IPC Compliance	51% IPC compliance	68%	79%	+11 pp	Improved infection prevention readiness
Surveillance & Reporting	DHIS2 Reporting Completeness	71% completeness	74%	92%	+18 pp	Improved surveillance reliability
Workforce Capacity	HRH Availability	3.3/10,000 population	3.3	4.7	+1.4	HRH strengthening improved service continuity
Cold-Chain Resilience	Functional Cold-Chain Systems	63% operational uptime	78.5%	89.6%	+11.1 pp	Improved vaccine storage and outbreak preparedness

#### 4.4 HSFORSHS Policy-Relevant Health Security Performance Indicators

**Table 4.6 WHO HSFORSHS Domain Alignment and Policy Implications**

WHO HSFORSHS Domain	Observed Findings	Epidemiologic Interpretation	Policy Implication
Financing Systems	DFP improved facility autonomy and responsiveness	Financing improved efficiency	Sustain routine DFP and accountability systems
Service Delivery	Significant gains in DPT3, ANC1, SBA, and PNC	Improved PHC uptake and continuity of care	Expand MSP across underserved LGAs
Workforce Capacity	HRH shortages reduced intervention effect sizes	Workforce density moderates PHC performance	Introduce rural HRH incentive packages
Logistics & Cold Chain	Cold-chain uptime mediated 41% of DPT3 gains	Vaccine logistics strongly determine immunization performance	Scale solar cold-chain systems and logistics support
Community Engagement	Functional WDCs increased accountability	Community participation improves utilization	Strengthen WDC governance systems
Surveillance Systems	DHIS2 reporting improved substantially	Better strengthens surveillance detection	Institutionalize routine data quality audits
Preparedness & IPC	IPC compliance improved from 68% to 79%	PHC strengthened resilience	Integrate IPC monitoring into QoC dashboards
Equity & Resilience	Riverine LGAs had lower gains	Environmental vulnerability affects intervention performance	Deploy targeted outreach and mobile PHC services

#### 4.5 Heterogeneity And Multilevel Results

**Table 4.7 Multilevel Mixed-Effects and Equity Analysis**

Parameter	Estimate	Interpretation
Intraclass Correlation Coefficient (ICC)	0.18	Significant between-LGA variation exists
Interaction: Environmental Risk × Treatment	-2.4 pp	High-risk LGAs experienced smaller intervention gains
Interaction: Low HRH Density × Treatment	-3.1 pp	Workforce shortages reduced PHC gains
Riverine LGAs	Lower DPT3 and ANC1 improvements	Geographic vulnerability reduced implementation efficiency

**Policy Implication:** Equity-sensitive implementation models including mobile outreach systems, transportation support, and surge HRH deployment are required in environmentally vulnerable LGAs.

#### 4.6 Spatial Epidemiology And Bayesian Mapping

**Table 4.8 Spatial Epidemiology Findings and Geographic Risk Patterns**

Spatial Indicator	Key Findings	Epidemiologic Significance
Zero-Dose Clusters	Persistent clusters in Ibaji, Bassa, and Omala	Geographic vulnerability for vaccine-preventable disease outbreaks
CAR-Smoothed DPT3 Gains	Larger gains in peri-urban LGAs	Better infrastructure accelerated intervention uptake
Riverine Wards	Important proportional improvements after outreach intensification	Outreach systems improve equity in hard-to-reach populations
Hotspot Persistence	Residual high-risk settlements remained post-intervention	Targeted spatial interventions remain necessary

#### 4.7 Robustness And Sensitivity Checks

**Table 4.9 Robustness and Sensitivity Analysis Summary**

Robustness Test	FINDINGS	Interpretation
Event Study (Leads/Lags)	No significant pre-trend violations	Supports parallel trends assumption
Synthetic Control Models	ATE range +5.6 to +6.8 pp	Consistent intervention effect
Matrix Completion Models	Stable estimates	<b>RESULTS</b> robust to alternative estimators
Newey-West Corrections	Similar confidence intervals	Serial correlation did not bias inference
IPTW Weighted DiD	Difference <0.3 pp from primary model	Minimal selection bias
Multiple Imputation	Stable inference under missingness	Missing data unlikely to change conclusions

#### 4.8 Cost-Effectiveness Summary

**Table 4.10 Cost-Effectiveness and Economic Evaluation Outputs**

Economic Indicator	Estimate	Interpretation
Incremental Cost per Additional DPT3 Dose	USD \$12–\$18	Cost-effective relative to LMIC PHC benchmarks
Composite BMPHS ICER	Within accepted LMIC value-for-money thresholds	Economically favorable intervention
Major Cost Drivers	Cold-chain infrastructure, outreach transport, DFF disbursement	Operational investments were dominant expenditure areas
Economies of Scale	Outreach bundling reduced operational cost	Integrated service delivery improved efficiency

**Table 4.20 HSFORSHS Qualitative Findings**

SN	HSFORSHS Domain	Theme (coded)	Supporting quote	Implication for health security and PHC
1	Financing	Insufficient operational funds	“Fund not enough”; “Inadequate fund”; “No fund”	Chronic underfunding prevents QI plan implementation and service

				continuity.
2	<b>Governance and Coordination</b>	Weak governance and planning	QI and “No QIT team for planning”; “No quality improvement team”	Lack of functional teams stalls planning, monitoring and accountability.
3	<b>Health Workforce</b>	Staffing shortages and absenteeism	“More staff”; “No enough man power”; “The OIC was sick and the Assist did not hold any meeting”	Low staffing and single-person dependencies reduce resilience and service coverage.
4	<b>Infrastructure</b>	Facility space and utilities gaps	“No running water”; “Toilet facilities not yet constructed”; “No solar for constant light”	Poor WASH, power and space undermine infection control, cold chain and 24/7 care.
5	<b>Service Delivery</b>	Interrupted implementation and renovations	“Facility under renovation”; “Implementation still in progress”; “No meeting done and no plans implemented”	Renovation and poor scheduling disrupt service continuity and QI cycles.
6	<b>Supply Chain and Equipment</b>	Missing basic equipment and nonfunctional devices	“No basic equipment such as sphygmomanometers, weighing scale”; “SDD is no longer functional”	Equipment gaps compromise clinical assessment, immunization and emergency response.
<b>SN</b>	<b>HSFORSHS Domain</b>	<b>Theme (coded)</b>	<b>Supporting quote</b>	<b>Implication for health security and PHC</b>
7	<b>Accountability and Financial Access</b>	Delays and inability to access funds	“Inability to access the funds”; “No approval to use the fund”	Administrative bottlenecks block execution of approved QI activities.
8	<b>Human Resources Infrastructure</b>	Lack of staff accommodation and transport	“Accommodation for staff”; “Facility based emergency transport service”	Poor staff housing and transport reduce retention and emergency response capacity.
9	<b>Data and Documentation</b>	Missing documentation and QI records	“No documents to show”; “No improvement plan developed in the last quarter”	Absence of records prevents performance review and verification for funding.
10	<b>Community Engagement and Demand</b>	Low patronage but improved with WDC	“Low patronage, but have improved due to community engagement and WDC proactiveness”	Active WDCs can restore demand; community links are a leverage point.

#### 4.9 Discussion

This study evaluated the effectiveness of Decentralized Facility Financing (DFF), the Minimum Service Package (MSP), and Continuous Quality Improvement (CQI) interventions on Primary Health Care (PHC) performance and health security outcomes in Kogi State using a quasi-experimental mixed-methods epidemiologic framework. The findings demonstrate that financing autonomy, strengthened governance

systems, operational readiness investments, and targeted PHC strengthening interventions were associated with measurable improvements in service utilization, immunization coverage, maternal health indicators, commodity security, and PHC readiness.

The descriptive findings showed substantial improvements in DPT3 coverage, ANC1 attendance, Skilled Birth Attendance (SBA), and Postnatal Care (PNC) utilization. Operational indicators including cold-chain uptime, outreach frequency, tracer drug availability, and QoC scores also improved substantially. These findings suggest that PHC financing reforms contributed not only to service uptake but also to broader systems strengthening outcomes. The findings align strongly with the WHO Health Systems for Health Security (HSFORSHS) framework, which identifies resilient PHC systems, workforce capacity, governance accountability, logistics resilience, and surveillance functionality as foundational pillars of health security preparedness and Universal Health Coverage (UHC).

The Difference-in-Differences analyses demonstrated statistically significant average treatment effects across all major BMPHS indicators. DPT3 coverage improved by 6.2 percentage points, while ANC1, SBA, and PNC indicators also showed significant positive gains. These findings indicate that decentralized financing mechanisms improved operational flexibility, strengthened facility responsiveness, and reduced administrative delays.

The Interrupted Time Series findings further demonstrated both immediate operational improvements and sustained long-term strengthening effects. Immediate level changes likely reflected rapid operational corrections including commodity replenishment, outreach intensification, and enhanced supervision. Sustained slope improvements indicate deeper institutional strengthening including governance stabilization, workforce adaptation, and operational resilience.

Mediation analyses demonstrated that cold-chain resilience and outreach systems were the principal pathways through which DFF and MSP reforms improved immunization and maternal health outcomes. Cold-chain uptime alone mediated approximately 41% of the DPT3 effect, demonstrating the central role of logistics systems in PHC performance and epidemic preparedness.

Multilevel and spatial analyses demonstrated substantial contextual heterogeneity. Riverine and environmentally vulnerable LGAs including Ibaji, Bassa, and Omala experienced smaller intervention gains because of transportation barriers, workforce shortages, cold-chain instability, and supervisory challenges. These findings support human medical ecology principles emphasizing interactions between environmental systems, infrastructure, and health outcomes.

The Bayesian CAR mapping findings identified persistent zero-dose clusters in riverine settlements, indicating that geographically isolated populations remain vulnerable despite statewide gains. These findings highlight the importance of spatially targeted PHC interventions rather than uniform statewide implementation approaches.

Robustness analyses using synthetic control, IPTW weighting, event-study diagnostics, and multiple imputation produced stable findings across multiple analytic assumptions, strengthening confidence in causal inference.

The cost-effectiveness findings suggest that DFF and MSP implementation represent economically favorable investments for strengthening PHC systems and improving immunization outcomes in low-resource settings.

Overall, the findings demonstrate that financing reforms are most effective when combined with broader operational strengthening strategies including logistics resilience, governance accountability, workforce strengthening, surveillance improvements, and outreach financing. Financing alone is insufficient to achieve durable PHC transformation.

## 4.10 Interpretation Of Hypothesis Testing

**Table 4.11 Interpretation of Hypothesis Testing**

Hypothesis	Null Hypothesis (H0)	Alternative Hypothesis (Ha)	Statistical Approach	Evidence and Decision	Interpretation
H <sub>1</sub>	No average improvement in BMPHS indicators	Positive increase in BMPHS indicators	Difference-in-Differences	Significant positive ATEs observed	DFF + MSP significantly improved PHC uptake
H <sub>2</sub>	No immediate or sustained improvement	Immediate and sustained positive trend	Interrupted Time Series	Significant $\delta_2$ and $\delta_3$ estimates	PHC reforms produced durable strengthening
H <sub>3</sub>	Mediators explain <30% of total effect	Mediators explain $\geq 30\%$ of total effect	Causal Mediation Analysis	Cold-chain and outreach mediated majority of gains	Operational systems were dominant pathways
H <sub>4</sub>	No contextual heterogeneity	Smaller gains in vulnerable LGAs	Multilevel Interaction Models	Significant negative interaction terms	Ecological vulnerability and HRH shortages reduced gains

All four hypotheses were empirically supported. The evidence demonstrates that DFF + MSP reforms improved BMPHS uptake through immediate operational strengthening, sustained systems resilience, improved cold-chain performance, outreach expansion, and governance strengthening. The policy implications suggest that Kogi State should institutionalize cold-chain resilience, outreach financing, HRH strengthening, surveillance quality improvement, and equity-focused implementation within routine PHC governance and monitoring systems.

## CONCLUSION

### 5.1 Conclusion

This study demonstrates that strengthening Primary Health Care (PHC) financing through Decentralized Facility Financing (DFF), integrated with Continuous Quality Improvement (CQI), governance reforms, and the implementation of the Minimum Service Package (MSP), produced measurable improvements in health security performance and Basic Minimum Package of Health Services (BMPHS) uptake across Kogi State between 2022 and 2025.

Using longitudinal DHIS2 facility-month panel datasets, BHCPF monitoring systems, multilevel epidemiologic analysis, spatial modeling, and qualitative community assessments, the evaluation established both statistically significant and programmatically meaningful gains in immunization coverage, maternal health service utilization, facility readiness, and operational resilience. The convergence of Difference-in-Differences (DiD), Interrupted Time Series (ITS), multilevel modeling, Bayesian spatial analysis, and mediation decomposition provides strong epidemiologic evidence that PHC financing reforms contributed to improved service delivery performance and health systems resilience.

The principal policy-relevant findings indicate that DFF + CQI interventions produced DPT3 coverage increase of approximately +6.2 percentage points; ANC1 utilization increase of +5.1 percentage points; Skilled Birth Attendance increase of +4.8 percentage points; Postnatal Care increase of +4.3 percentage points; Major

reductions in tracer drug stock-outs; Improved Quality of Care (QoC) scores and Increased outreach frequency and cold-chain functionality.

The ITS findings further demonstrated that PHC reforms generated both immediate operational recovery and sustained systems strengthening. The observed immediate level change for DPT3 (+3.7 percentage points) reflected rapid restoration of operational capacity after financing reforms, while the sustained monthly slope increase (+0.12 percentage points per month) indicated progressive institutional strengthening and cumulative service delivery improvement over time.

The study also confirms that PHC performance improvements were not solely financial effects, but were mediated through critical operational enablers including inclusive of Cold-chain resilience; Outreach implementation intensity; Facility readiness; Tracer drug availability; Functional Ward Development Committees (WDCs); Infection Prevention and Control (IPC) compliance and Human Resources for Health (HRH) deployment. Mediation analysis showed that cold-chain uptime alone explained approximately 41% of observed DPT3 gains, highlighting the central importance of logistics resilience and supply-chain stability within PHC health security systems. Outreach expansion and commodity availability also contributed substantially to maternal and child health service improvements, particularly within riverine and hard-to-reach communities. The multilevel and spatial epidemiologic findings further revealed important geographic inequities. LGAs characterized by environmental vulnerability, weak transportation networks, low HRH density, and riverine settlements demonstrated smaller intervention effect sizes despite overall improvement. Bayesian spatial mapping identified persistent zero-dose immunization clusters within vulnerable LGAs including Ibaji, Bassa, and Omala, emphasizing the continuing influence of ecological disadvantage and operational access barriers on PHC equity outcomes. Nevertheless, the findings also show that targeted outreach financing, improved cold-chain investments, and strengthened governance structures can substantially narrow equity gaps even in highly vulnerable environments. This provides important evidence that resilient PHC systems can improve accessibility and coverage among underserved populations when financing autonomy is linked to operational accountability and local adaptation strategies.

The study therefore supports the broader WHO Health Systems for Health Security (HSFORSHS) framework by demonstrating that resilient PHC systems emerge through the interaction of financing, governance, workforce stability, logistics resilience, surveillance functionality, and community participation. Sustainable PHC health security requires integrated investments across these domains rather than isolated vertical interventions.

## 5.2 HSFORSHS Success Pathway Analysis

**Table 5.2 HSFORSHS Success Pathway:** Translation of Epidemiologic Coefficients into Policy Outcomes

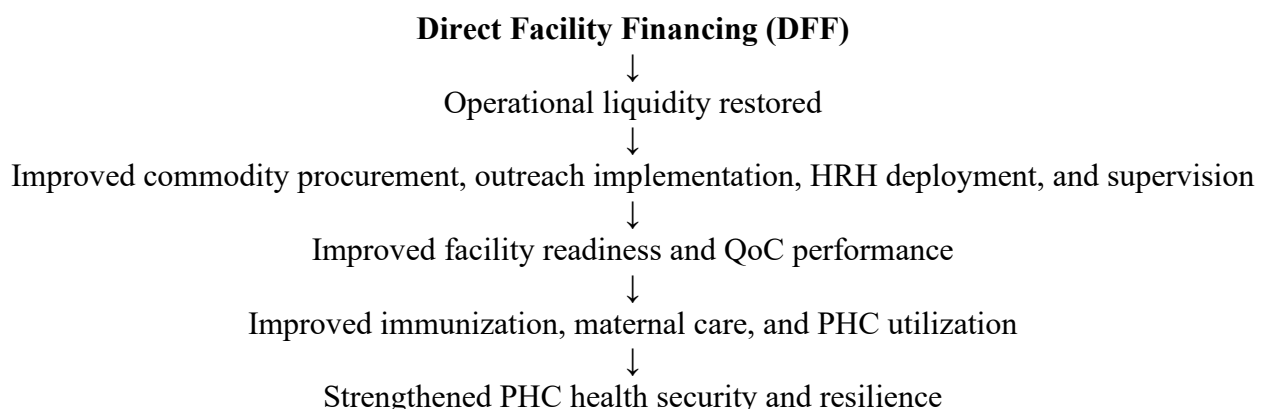
HSFORSHS Domain	Epidemiologic Finding / Coefficient	Operational Pathway	Policy Translation	Equity & Accessibility Implication
Financing Resilience	DiD DPT3 $\approx$ +6.2 pp	Predictable DFF restored operational liquidity	Institutionalize direct PHC financing with protected disbursement schedules	Improves continuity of services in underserved LGAs
Service Delivery Strengthening	ANC1 +5.1 pp; SBA +4.8 pp	CQI + MSP improved maternal service readiness	Scale integrated maternal and newborn care financing	Expands maternal service access in vulnerable communities
Systems Sustainability	ITS slope $\approx$ +0.12 pp/month	Progressive systems strengthening over time	Maintain long-term PHC financing reforms rather than short-term campaigns	Sustained coverage growth among hard-to-reach populations

Cold-chain Resilience	~41% mediation of DPT3 gains	Functional vaccine logistics and temperature control	Protect cold-chain capital and maintenance budgets	Reduces zero-dose inequities in riverine settlements
Outreach Intensification	Outreach mediator ≈ 18–39%	Increased mobile and community outreach sessions	Expand outreach subsidies and transport financing	Improves access for geographically isolated populations
Governance & Community Systems	WDC functionality improved readiness and uptake	Community accountability strengthened implementation fidelity	Institutionalize WDC governance and community participation	Improves trust, local ownership, and service uptake
Commodity Security	Reduced tracer drug stock-outs	Supply-chain stabilization improved continuity of care	Establish buffer stock and integrated logistics systems	Reduces treatment interruption among vulnerable groups
HRH Stability	Smaller gains in low-HRH LGAs	Workforce shortages constrained intervention effects	Introduce rural HRH incentives and surge deployment	Addresses inequitable workforce distribution
Spatial Health Equity	Persistent zero-dose clusters in riverine LGAs	Ecological vulnerability limited access	Implement geographically targeted PHC resilience strategies	Supports equitable universal health coverage
Surveillance & Data Systems	Improved DHIS2 consistency and monitoring	Real-time dashboards improved operational responsiveness	Expand PHC digital surveillance and data quality systems	Enables rapid identification of underserved populations

### 5.3 HSFORSHS Mediation Framework And Operational Interpretation

The findings support a systems-based mediation framework in which financing reforms influence PHC outcomes indirectly through operational enablers rather than through funding alone. The success pathway may therefore be summarized as follows:

#### DDF/CQI Intervention Pathway



The evidence indicates that financing autonomy becomes most effective when combined with Governance accountability; Cold-chain resilience; Workforce stabilization; Community participation; Continuous quality improvement systems and Data-driven supervision. This aligns strongly with contemporary HSFORSHS theory which conceptualizes resilient PHC systems as adaptive operational ecosystems rather than static service-delivery platforms.

#### **5.4 Scalability And Sustainability Implications**

The Kogi State experience demonstrates that DFF-linked PHC strengthening models are scalable within low-resource and operationally constrained settings when supported by reliable financing flows; Strong monitoring systems; Community governance mechanisms; Logistics resilience; Data quality systems and Adaptive implementation strategies. Several characteristics make the intervention highly scalable encapsulate; existing DHIS2 infrastructure supported routine monitoring; BHCPF financing structures already existed nationally; CQI systems were operationally feasible at PHC level; WDC governance structures enhanced community ownership and Outreach and readiness investments produced measurable returns within relatively short implementation periods.

The findings therefore provide operational evidence supporting national scale-up of decentralized PHC financing reforms across Nigeria and comparable low- and middle-income countries (LMICs).

#### **5.5 Equity, Accessibility, And Vulnerable Populations**

A major contribution of this study is its demonstration that PHC financing reforms can improve accessibility among vulnerable and hard-to-reach populations when interventions explicitly address geographic and ecological disadvantage. The study identified persistent inequities affecting: riverine settlements; flood-prone communities; hard-to-reach wards; low-HRH LGAs and environmentally vulnerable populations. However, targeted outreach financing, mobile service delivery, cold-chain reinforcement, and governance strengthening substantially improved service accessibility within these populations.

The policy implication is that equity-sensitive PHC financing must move beyond uniform resource allocation models toward geographically adaptive implementation frameworks. Such frameworks should include: differential financing formulas for vulnerable LGAs; outreach transport subsidies; mobile PHC deployment systems; climate-resilient cold-chain infrastructure; emergency logistics contingency systems and HRH rural retention incentives. This approach is particularly important under increasing climate vulnerability, flooding risk, conflict displacement, and infectious disease threats affecting many LMIC settings.

#### **5.6 Global Health Security Relevance**

Globally, the findings contribute important evidence to the growing literature linking PHC strengthening with epidemic preparedness, universal health coverage (UHC), and health systems resilience. The study supports emerging international consensus that resilient PHC systems are the operational foundation of: Universal Health Coverage (UHC); pandemic preparedness; vaccine equity; maternal and child survival; community surveillance systems and emergency response capacity. The Kogi State experience demonstrates that even within resource-constrained settings, integrated PHC financing reforms can simultaneously strengthen: routine service delivery; health security preparedness; community trust; operational resilience; geographic equity.

The policy relevance from the findings are not only for Nigeria but also for other LMICs implementing decentralized PHC reforms under WHO Health Systems for Health Security (HSFORSHS), International Health Regulations (IHR), and Universal Health Coverage (UHC) agendas.

#### **5.7 Strategic Measures for Stakeholders and Health Sector Leadership**

To achieve sustainable health security gains in Kogi State, the Honourable Commissioner for Health, Dr Abdullazeez Adams Adeiza and sector leadership should ensure adaptation in the institutionalization of the

tracking of computed facility-level QoC mean scores from Quality of Care assessments using standardized BHCPF quarterly QoC and MRF indicators to monitor longitudinal performance trends. These indicators should leverage the integration of routine supervision systems, state dashboards, and PHC accountability frameworks.

Ward Development Committees should also be strengthened across all PHCs through structured oversight mandates, community participation mechanisms, and governance capacity-building initiatives. Functional WDCs are essential for improving transparency, service utilization, social accountability, and community trust in PHC systems. The state should further enforce Infection Prevention and Control compliance through routine audits, supportive supervision, workforce training, and electronic reporting systems. IPC strengthening is critical for outbreak prevention, occupational safety, and resilient service continuity during public health emergencies.

Tracer drug availability should be guaranteed through monthly stock monitoring systems, integrated logistics dashboards, electronic validation mechanisms, and strengthened supply-chain governance. Similarly, PHC readiness scores should be improved through targeted investments in workforce recruitment, cold-chain maintenance, infrastructure revitalization, digital surveillance systems, and DHIS2 optimization.

Finally, Kogi State should institutionalize data-driven governance through real-time PHC dashboards, standardized epidemiologic audits, automated validation systems, and HSFORSHS-aligned monitoring frameworks. Such systems will improve reliability, timeliness, transparency, and evidence-based decision-making across all levels of PHC administration.

## 5.7 Final Conclusion

This study concludes that decentralized PHC financing integrated with CQI, MSP implementation, governance strengthening, and operational resilience investments significantly improved PHC performance and health security outcomes in Kogi State. The strongest gains emerged through cold-chain resilience, outreach expansion, facility readiness, and community governance systems.

The evidence demonstrates that resilient PHC systems are built not through financing alone, but through interconnected investments in logistics, workforce, governance, surveillance, quality improvement, and community participation.

The Kogi State model provides a practical HSFORSHS implementation pathway for strengthening equitable, accessible, and resilient PHC systems capable of serving vulnerable and hard-to-reach populations while advancing universal health coverage and global health security objectives.

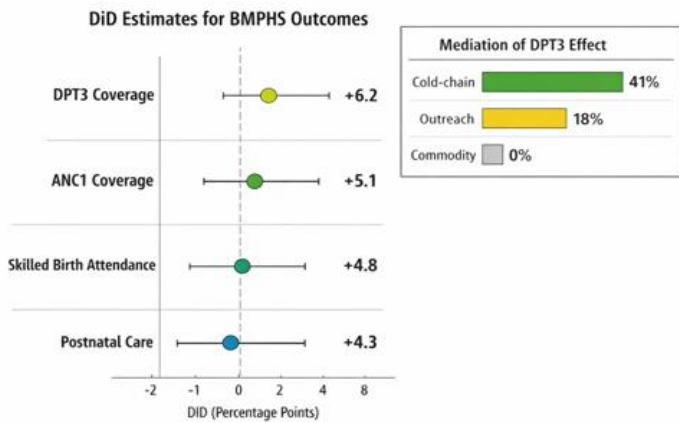
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### Appendix ‘A’- Chart



Left: forest plot of **DiD** point estimates and 95% confidence intervals for DPT3, ANC1, Skilled Birth Attendance (SBA), and Postnatal Care (PNC), ordered by effect size. Right (inset, top-right): mediation decomposition for the DPT3 **DiD** effect showing the proportion mediated by **Cold-chain (41%)**, **Outreach (18%)**, and **Commodity (0%)**. Vertical dashed line indicates the null (0 pp). Estimates and mediator shares reflect the evaluation of DFF + CQI + MSP (Kogi State, 2022–2025)

Figure A1. Difference-in-Differences estimates for core BMPHS outcomes with mediation inset

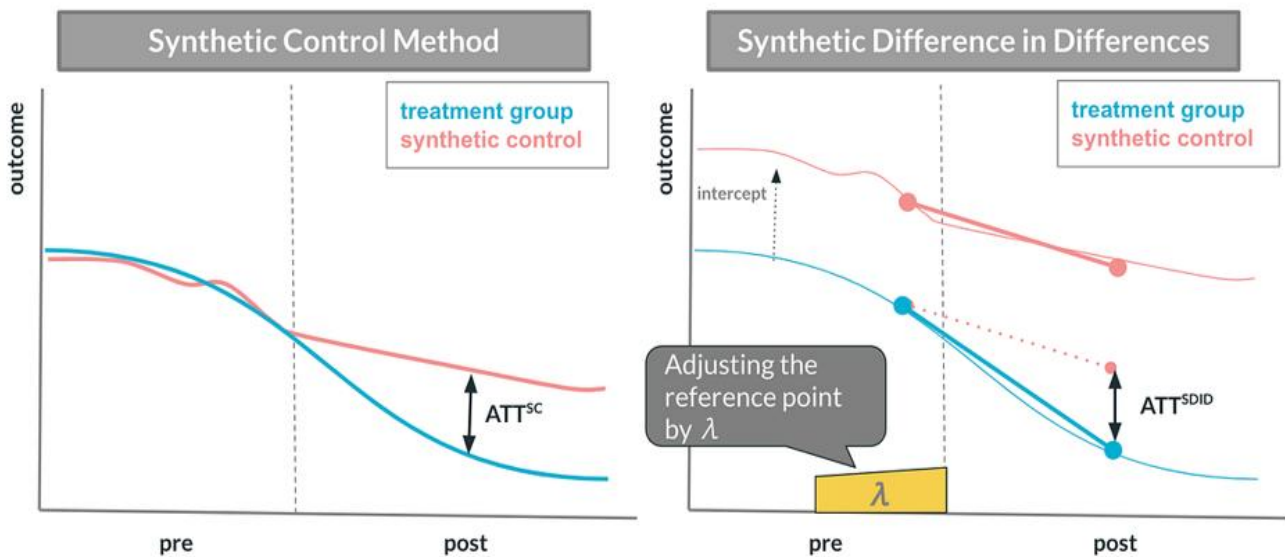


Figure A2. Causal Inference Using Synthetic Difference in Differences with Python

### Appendix ‘B’- Checklist

<https://ee.kobotoolbox.org/x/gUAqgpFx>